

The Z Transverse Momentum Distribution

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The DØ collaboration has measured the transverse momentum of the Z boson in the process $Z/\gamma^* \rightarrow ee$. This is compared to a theoretical model of the boson transverse momentum and found to agree well with the existing parametrization. This parametrization is a critical input in the measurement of the W boson mass measurement, which is discussed briefly.

1 Introduction

At leading order W and Z bosons are produced at the Tevatron predominately through the Drell-Yan diagrams shown in figures 1 and 2, where the only particle in the final state is the boson. Without anything to recoil against the boson is necessarily produced at rest in the $q\bar{q}$ frame. The partons themselves are assumed to have very little momentum transverse to the beam direction (from the confinement of the parton within the proton). Therefore the boson is produced with effectively no p_T .

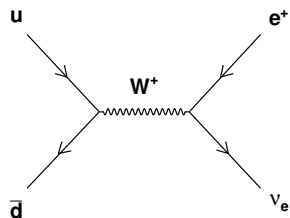


Figure 1: W boson production and decay at tree level.

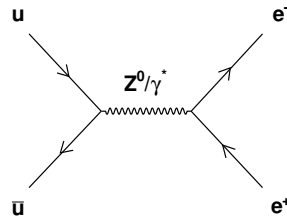


Figure 2: Z/γ^* production and decay at tree level.

Higher order quantum chromodynamics (QCD) processes involve additional particles in the final state. The most straightforward to consider are the initial state radiation of a gluon (ISR)

and the Compton radiation of a gluon (figure 3). This additional particle gives the boson something to recoil against. Typically this results in a boson p_T of several GeV.



Figure 3: W boson production at next to leading order. Here the boson recoils against the gluon, resulting in non-zero boson transverse momentum.

2 Boson Production

A complete discussion of the p_T distribution of electroweak bosons at production is a significant undertaking, the full details of which are beyond the scope of this discussion. However, because of the critical role the description of boson production plays in the measurement of the W boson mass, as well as searches for production of the Higgs boson and other beyond the Standard Model physics, we describe several of the important phenomenological details. The differential cross section with respect to the boson transverse momentum is written as

$$\frac{d^2\sigma}{dP_T^2} = \sum_{ij} \int dx_1 dx_2 f_i(x_1) f_j(x_2) \frac{d^2\sigma(ij \rightarrow V)}{dP_T^2}. \quad (1)$$

For the process $q\bar{q} \rightarrow W\bar{q}$ shown in figures 3 one can accurately calculate the transverse momentum distribution at high p_T ($p_T \approx M_{\text{Boson}}$) using perturbative QCD. In the low p_T region the results are divergent. A framework was developed by Collins, Soper and Sternman¹ to re-sum the perturbation series by grouping the divergent, non-perturbative terms together. This re-summation works for all orders in perturbation theory but requires a correction at low- p_T where non-perturbative physics becomes important. The correction is parameterized with a function W that smoothly turns off as the boson p_T increases. The parton level cross section is then

$$\frac{d^2\sigma(q\bar{q} \rightarrow V)}{dP_T^2} \sim \int_0^\infty [d^2b e^{i\vec{P}_T \cdot \vec{b}} \times W(b, Q)] + Y(P_T, Q) \quad (2)$$

where Y is the perturbative piece and the impact parameter b is the conjugate variable of p_T (as b increases p_T decreases). The form of the W function is phenomenologically motivated and is determined by fitting data from several experiments. Recently the form

$$W_{NP}(b) = \exp\left(-\left(g_1 + g_2 \ln\left(\frac{Q}{2Q_0}\right) + g_1 g_3 \ln(100x_1 x_2)\right) b^2\right) \quad (3)$$

was proposed by Brock, Landry, Nadolsky and Yuan², where in this case

$$Q \sim 91\text{GeV}, \quad Q_0 = 1.6\text{GeV}, \quad x_{i,j} \sim 0.05 \quad (4)$$

and the parameters

$$g_1 = 0.21 \pm 0.01 \text{ GeV}^2 \quad g_2 = 0.68^{+0.01}_{-0.02} \text{ GeV}^2 \quad g_3 = -0.60^{+0.05}_{-0.04} \quad (5)$$

are determined through global fits. In the kinematic region we are interested in the g_2 term dominates. Independent of the global fits the DØ experiment uses the transverse momentum spectrum of $Z \rightarrow e\bar{e}$ decays to determine g_2 .

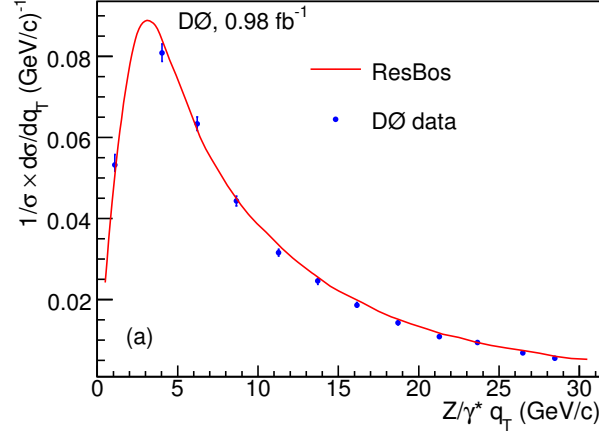


Figure 4: Z/γ^* transverse momentum distribution with boson $|y| < 2.0$. The points are the data and the solid line is the ResBos prediction.

3 Z Transverse Momentum Analysis

The event selection used to collect Z boson candidates requires two isolated electromagnetic (EM) clusters that have a shower shape consistent with that of an electron and are away from the module boundaries of the calorimeters. Electron candidates are required to have transverse momentum greater than 25 GeV. The pairs of electrons must have an invariant mass $70 < M(ee) < 110$ GeV. If both electrons are in the central calorimeter, then each electron must be spatially matched to a reconstructed track. The central section of the calorimeter has coverage for electrons of $|\eta| < 1.1$ and two endcap calorimeters have an approximate coverage of $1.5 < |\eta| < 3.2$ for electrons ($\eta = \ln[\tan(\theta/2)]$). In figure 4 the Z boson p_T distribution is shown corrected for efficiencies, background and acceptance and then unfolded to obtain the true differential cross section³. The curve is the ResBos^{4 5 6} prediction using the BLNY parametrization.

We fit for the parameter g_2 using the distribution in figure 4 and find the best fit value to be $g_2 = 0.77 \pm 0.06$. This is then used as an input in the measurement of the W mass.

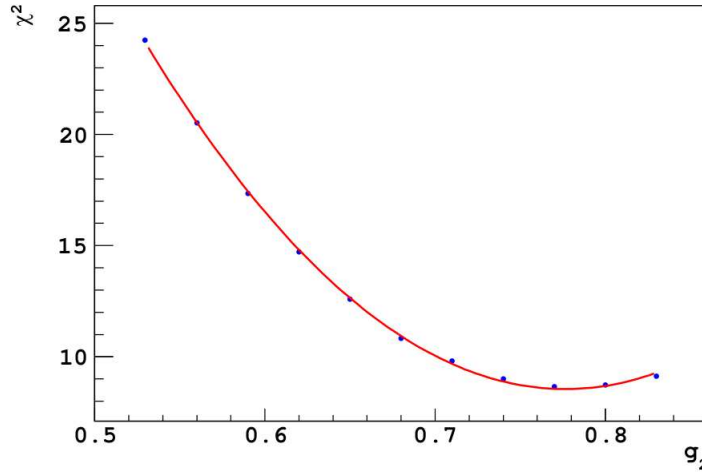


Figure 5: The χ^2 as a function of the g_2 parameter using the unfolded data and the BLNY model. The solid line is a polynomial fit.

4 Implications for W Mass Measurement

To measure the W boson mass using the $W \rightarrow e\nu$ decay channel a theoretical description of the boson's transverse momentum is necessary. This is because the invariant mass cannot be reconstructed from the electron/neutrino final state. Instead, the sensitivity of the electron transverse momentum and the transverse mass (analogous to the invariant mass) distributions to the W boson mass are exploited. The electron p_T and the transverse mass distributions cannot be described analytically so a theoretical description of the boson production and decay is employed, in conjunction with a parameterized detector simulation. Using the parametrization in [5] with the value for the g_2 parameter determined above we estimate the contribution to the overall uncertainty on the W boson mass at DØ (using approximately 1 fb^{-1} of data) to be 5 MeV for the transverse mass distribution and 16 MeV for the transverse momentum distribution. With a total estimated statistical uncertainty of 17 MeV using the transverse mass distribution (23 MeV using the electron p_T distribution) for this sample this aspect of the theoretical description is not the dominate uncertainty.

Acknowledgments

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